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(71) Applicant: RADIO PROGRAMMES CORP. [US/US]; 98 Old Albany Post Road, Garrison, NY 10524 (US).

(72) Inventors: RANDERS-PEHRSON, Gerhard; 196 Shonnard Terrace, Yonkers, NY 10701 (US). BRENNER, David, J.; 139 West 82nd Street, New York, NY 10024 (US).

(74) Agents: LAWRENCE, William, F. et al.; Curtis, Morris & Safford, P.C., 530 Fifth Avenue, New York, NY 10036 (US).

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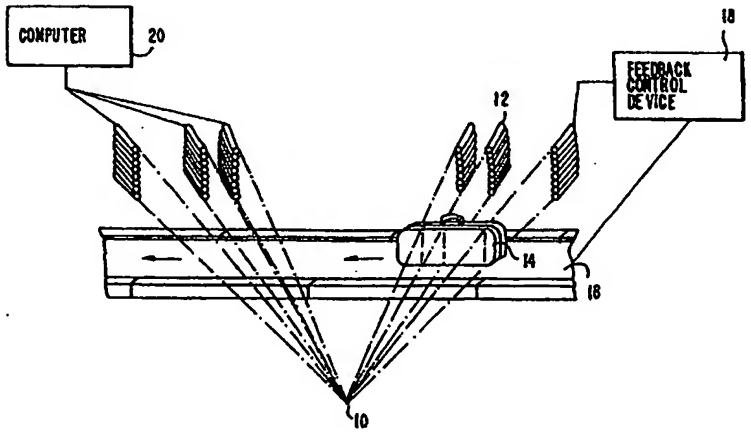

(57) Abstract

A method and apparatus for non-invasively determining the internal composition of objects are disclosed. The object of interest (14) is probed with low energy, monoenergetic narrow beams of fast neutrons. The object (14) is generally placed on a conveyor belt (16) which is positioned between the accelerator (10) and the detectors (12). Detectors (12), positioned at radial angles corresponding to the resonance energy levels of certain preselected elements, measure the neutrons that are not absorbed or scattered by the elements in the object (14) and thus pass straight through the object (14). The information obtained from the detectors (12) can then be used for subsequent tomographic reconstruction.

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TITLE OF THE INVENTION

Substance Detection Device
Using Monoenergetic Neutrons

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application Serial No. 60/016,578, filed April 30, 1996.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to methods and apparatus for non-invasively determining the composition of objects, particularly closed containers or otherwise inaccessible objects. More particularly, the present invention relates to a method and apparatus that uses neutron scattering to identify the existence of particular elements that are abundant in explosives.

Description of the Invention

The need exists for a rapid, safe, accurate and non-intrusive inspection system for determining the presence of certain elements in objects such as suitcases and luggage. This need is especially great for identifying the presence of explosives or explosive devices in suitcases or any other parcel to be brought upon an airplane.

It is well known that essentially all explosives are both oxygen and nitrogen rich. One way to detect concealed explosives is to use penetrating radiation, such as neutrons, and to detect the interaction of the neutrons with oxygen and nitrogen atoms.

Uncharged particles, such as neutrons and photons (gamma rays) have the potential to penetrate relatively large dense objects and to identify particular elements of interest. Several detection devices have

utilized the absorption and/or scattering patterns of the neutrons or photons as they interact with certain elements present in the object being inspected.

A number of the processes used to detect concealed explosives have irradiated suspicious containers with thermal neutrons or, alternatively, with pulsed fast neutrons. Both systems measure the emitted gamma rays produced by the absorption of a neutron by the element of interest. The techniques have involved thermal neutron analysis (TNA) described by R.R. Smith in *Substance Detection Systems*, Proc. SPIE 2092, pp. 301-306 (1994) and pulsed fast neutron analysis (PFNA) described in *Nucl. Inst. and Meth.* B 79: 593-596 (1993) by Z.P. Sawa.

In thermal neutron analysis systems ("TNAS"), very low energy neutrons (at or about .025 eV) are employed to bombard a sample under investigation. The nuclei of component atoms capture these neutrons and emit photons which are then detected. A significant problem with this method is that the radioactivity may persist for a period of time presenting a potential health hazard. In addition, TNAS exhibit both poor spatial resolution and poor sensitivity and are generally only potentially practical for detecting relevant quantities of explosives when used in combination with x-ray machines.

Pulsed fast neutron analysis is limited in resolution and detection time due to neutron attenuation and scattering, detector response time, and time correlated effects such as gamma ray scattering. In addition, a complex high-energy pulsed accelerator is needed, in conjunction with time-of-flight systems.

Gamma ray nuclear resonance absorption (GNRA) described in *Substance Detection Systems*, Proc. SPIE 2092, pp. 307-316 (1994), is a method which probes a single element (typically nitrogen) with gamma rays of a particular energy. The gamma rays excite the nitrogen

nucleus which promptly returns to its lowest energy state, emitting a cascade of gamma rays in the process. Detecting the cascade signals the presence of nitrogen. This technique can only practically detect a single element, generally nitrogen. Thus, it is far more prone to false alarms than a multi-element detection system which includes, at a minimum, nitrogen and oxygen.

Fast neutron transmission spectroscopy (FNTS) is another nuclear detection method used to identify particular elements of interest. FNTS, as described in Overley J.C. et al., *Nucl. Instr. and Meth.* B99:728-732 (1995) and Sale, K.E., *Substance Detection Systems*, Proc. SPIE 2092, pp. 263-270 (1994), uses a high intensity pulsed polyenergetic neutron beam. An attenuated neutron energy spectrum is assessed by time of flight. There are a number of significant drawbacks to using this inspection system due to the fairly complex high energy pulsed accelerator that is needed in conjunction with a time of flight system. In addition, sensitivity is quite limited because a fairly small decrease in the overall unattenuated signal is sought in a field in which there are significant background signals from neutron scattering. United States Patent No. 5,142,153 to Gomberg, discloses a method and apparatus for detecting the presence of a preselected element in an object such as a suitcase. In this particular system, a neutron beam is directed into the object and the neutrons that are resonantly scattered by the preselected element are measured. Since it is the scattered neutrons that are being measured, banks of detectors are needed at a variety of locations depending on the direction of the scattering. The detectors used are standard neutron detectors containing a neutron responsive material as well as a sensitive material having a resonance at a preselected energy.

United States Patent No. 5,278,418 to Broadhurst describes a method for detecting the presence

of oxygen and nitrogen in a container. High energy neutrons are passed through a suitcase. The neutrons that penetrate the object of interest and pass through to the other side are detected. The detectors used are standard neutron detectors. The accelerator focuses a proton beam upon a boron target in order to create the neutron beam. The proton beam is periodically subjected to an energy degrading medium upstream of the neutron generating target in order to modify the energy of the protons and thus to change the energy of the neutrons so that different elements can be detected. A major disadvantage of this approach to changing the energy of the neutron beam is that proton multiple scattering inside the degrading medium produces a non-monoenergetic proton beam and thus a non-monoenergetic neutron beam.

Each of the explosive detector systems described has significant drawbacks or disadvantages. In particular, these devices generally utilize accelerators that produce high energy neutrons with a broad spectrum of energies. The absorption/scattering of neutrons traveling at specific energies are difficult to detect given the large number of neutrons that pass through the object without interaction. Thus, the "fingerprint" generated from the device is extremely small, difficult to analyze, and often leads to significant numbers of false positive or false negative test results. In addition, the accelerator needed to produce the high energy neutron spectrum is large, expensive, and requires extensive protective shielding. Moreover, at these high energies, the neutrons can induce nuclear reactions in the element being scanned and convert the elements of the object into a radioactive form (neutron activation).

"Time-of-flight" detection techniques are frequently employed in PFNA and FNTS to provide energy discrimination to high energy neutron detectors. In time-of-flight detection, pulses of neutrons are directed onto an object. A detector is activated in

synchrony with each pulse so as to sample (measure) the scattered or transmitted neutrons on a temporal and hence energetic basis. Due to their complexity, time-of-flight techniques are problematic for large-scale explosive detectors and require a pulsed neutron source, fairly large source/detector geometries (i.e., a long flight path) and sophisticated timing circuitry. The long-term reliability of such systems is particularly uncertain.

The apparatus of the instant invention addresses the problems inherent in other devices and provides a detector system which uses low energy monoenergetic fast neutrons to identify the number and spatial distribution of specific elements in the object being examined. The use of monoenergetic neutrons results in a number of significant advantages over these other methods of explosive detection. The use of low fast-neutron energies requires a comparatively low energy proton beam for the neutron generating reactions. This allows for a small, simple, economical and reliable accelerator system. The generation of low energy fast-neutrons also can allow a correlation between the angle of the neutron beam and the outgoing neutron energy, so that monoenergetic neutron beams can be utilized. Such exact angle/energy correlations disappear at higher energies.

Further, because low-energy fast neutrons are used and time-of-flight analysis is not required, and because the apparatus does not require extensive protective shielding, the physical "footprint" of the equipment is small. Furthermore, because only monoenergetic neutrons are used, which correspond exactly to large resonances in the nitrogen and oxygen interaction cross sections (interaction probabilities), the signal to noise ratio of the system is favorable, leading to high sensitivity and specificity for quantitatively detecting the elements of interest. Furthermore, at there low fast-neutron energies, neutron

activation and the subsequent conversion to radioactive elements does not occur with the neutron used in this invention. These and other advantages of the invention will be readily apparent from the drawings, discussion and description which follow.

The contents of any references cited in the specification are hereby incorporated by reference.

SUMMARY OF THE INVENTION

It is thus an object of the invention to provide a novel method for detecting the presence of certain elements in a container or other object. More specifically, it is an object of this invention to provide a novel nuclear detection method and apparatus for detecting the presence of characteristically high levels of oxygen and nitrogen in a region within a container, as a screening technique for determining the presence of an explosive, in parcels and baggage that are transported by passenger aircraft.

The present invention relates to a neutron resonance detector system that uses neutron out-scattering to identify the existence of certain elements that are present in the object being examined. The device includes an accelerator which produces monoenergetic low energy fast neutrons at several specific energies, and detectors which measure monoenergetic neutrons which have passed unscattered through the object of interest. The object to be scanned is positioned between the accelerator and the detecting device. Neutrons that pass through the object unscattered are detected by the device.

In carrying out this invention, monoenergetic neutron beams at several specific energies are directed onto the object to be examined. At these low energies and with appropriately chosen neutron production targets, each angle of the neutron beam produced at the target corresponds to a particular neutron energy. The detectors, present at specific angles corresponding to

the neutron energies of large resonances (peaks) in the total neutron cross sections of the elements being detected, measure the number of neutrons that pass through the object unscattered. If large amounts of an element are present in some part of the object, the nuclei of that element will scatter neutrons traveling at the specified energy and thus fewer neutrons will pass unscattered through that part of the object being examined. The device compares the number of neutrons which enter the object versus the number of the neutrons that exit the remote side and are detected by the device. What is being measured is thus the inclusive removal of neutrons of specified energies from their initial energy and direction by all nuclear processes by the material (elements) inside the object. Based on this information, a computer connected to the detectors can first calculate the density of the elements being detected along the path of the unscattered neutrons, and then, based on this information for all the measurements taken along different paths though the object of interest, a computer connected to the detectors can then perform the calculations for tomographic unfolding. This provides a "picture" of the densities of specified elements in the object of interest. Furthermore, the computer can provide an integrated measure of nitrogen and oxygen densities across different planes in the bag, as well as the entire bag, in order to detect substances in thin sheet form.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in greater detail with the aid of the following figures.

Fig. 1 is a scatter-plot of densities of oxygen and nitrogen in various materials, including explosives.

Fig. 2 is total neutron cross sections for different elements in the energy range from 0.3 to 0.5 MeV. The full curve is nitrogen, showing a narrow